

Investigating Social Conflicts Linked to Water Resources through Agent-Based Modelling

Mehdi SAQALLI ^{a,1}, Samuel THIRIOT ^b and Frédéric AMBLARD ^{b,c}

^a *LMTG-Observatoire Midi-Pyrénées, Toulouse, France*

^b *CNRS-IRIT, UMR 5505, 114 route de Narbonne, 31042 Toulouse, France*

^c *Université Toulouse 1 Capitole, 2, rue du Doyen Gabriel Marty, 31 042 Toulouse Cedex 9, France*

Abstract. Over the next decades, natural resources and water resources in particular are likely to be one of the major origins of social conflicts. To date however, no model enables the study of coupled dynamics of hydrology, water use and social conflicts. Building such a model requires identifying the key concepts, entities and processes that are present in much field cases and have to be included into the model. The research presented in this paper takes place in a more general project named MAELIA for Multi-agent for Environmental Norms Impact Assessment. The purpose of MAELIA is to provide a decision-support model helping decision makers and stakeholders to manage water resources. This model aims to be generic enough for it to be applied in various field cases at different scales. We describe the actors involved in water management or water use using an agent-based approach. Water monitoring institutions and water users are described as agents in interaction within a stylised representation of a watershed basin. We propose a conceptual model that describes not only the hydrology in the basin and the water consumption behaviour of users, but also the representation of both the users at the institutional level and the power relationships that determine the arbitration of norms about water use. We propose two possible uses of this model. The first is the analysis of the impacts of several norms for detecting potential conflicts. The second possible use explores the local formulation of norms given the balance of powers in already settled social conflicts. This generic platform modelling conflicts on natural resources may thereby provide new insights into the analysis of well-known natural resource related conflicts, such as the Gauvery dispute in India.

Keywords. Social conflict, agent-based modelling, water resources, balance of powers

Introduction

Water resources will be a part of the most important global and environmental issues over the next decades. Among the salient issues concerning water resources the main one could be seen as a contradiction, the global amount of available water resources would increase significantly but the local troubles linked to the lack of water resources

¹ Corresponding Author : LMTG-Observatoire Midi-Pyrénées, 14, avenue Edouard Belin, 31400 Toulouse, France. E-mail : saqalli@lmtg.obs-mip.fr.

may also increase or at least lead to huge and often rough negotiations [1; 2]. In fact, this is not a contradiction as the main problem deals with *the availability of water* – where natural sources of fresh water will tend to decrease; *its repartition* – some world regions would see their situation getting worse concerning the availability of water; and some *changes in the climatic events* – violent events like storms and flood could tend to become more frequent [3]. For illustration purpose, the envisaged situation, particularly from the GIEC group, could be seen as a phase transition from a quite homogeneous repartition of water in space and time with natural tanks to a more heterogeneous one where natural tanks will tend to disappear at the same time as the heterogeneity in water availability over the world will tend to increase as well as its heterogeneity in time.

Envisaging such evolution of the water resources, this could have major social and economic impacts leading potentially to phenomena like climatic refugees as well as conflicts linked to water resources, control and dependency. As an example, the situation of the Jordan River running from the Syrian Golan along Israel, the occupied Territories and Jordan, and which supposed to flow into the Dead Sea, could be seen as a potential source of international conflicts in this region [4]. Apart of this particular situation and at more local scales, the day to day management of water resources for different purposes by different social actors could easily lead to situations where the full satisfaction of every need is no more possible and choices have to be made collectively to sort the different water usages [5]. Among those usages, the fresh water consumption by citizens, the irrigation by farmers and the use of water to produce electricity will probably have to be coordinated.

Facing such a situation, the classical tools and methods concerning the evaluation of water availability, its optimal dynamical allocation among the different usages, and cost-benefit analysis of the different management scenarios envisaged are for sure useful to try and to determine regulation solutions at a global scale, including normative (promulgation of rules concerning water usages) and prescriptive (putting objectives at a more local scale in terms of water resources availability) solutions. Such tools and methods involve models concerning the water resource dynamics, i.e. biophysical modelling approaches as well as classical environmental economics [6]. However, such tools and methods do not enable to evaluate clearly the efficiency of such solutions, the compliance of local actors towards the envisaged solution being crucial for the solution to become effective [7].

Therefore there is a need for a tool that would enable to couple the biophysical aspect of the problem and the socio-economical aspects, taking into account the actual usage of the different field actors as well as the way they may apply the prescriptions. Following [8], on the one hand, such a tool would enable anticipation of the potential bias linked to an envisaged normative or prescriptive solution and then to counter them, and on the other hand it could also enable determining which negotiation structure concerning the normative and prescriptive aspects has more chances to result in more efficient results by the implication of field actors into the negotiation of the solution [9]. Such a tool necessary implies an interdisciplinary research among domains that do not usually interact together, such as social and biophysical sciences.

The MAELIA (Multi-agent for Environmental Norms Impact Assessment) project aims at tackling this problem. In an interdisciplinary research context, the project aims at producing a multi-agent simulation platform that would help the policy-maker to assess the impact of new environmental norms and prescriptions on a socio-environmental system and help in determining how to better involve field actors in the

decision-making process to insure a better efficiency of norms and prescriptions negotiated. This paper summarises a descriptive approach of the existing system explored during the start of the project focusing on the Adour-Garonne basin in the south of France.

In the first section, we describe the modelling approach adopted and highlight the required properties of the model. We then (section 2) describe the Adour-Garonne field case, which is used to determine the various entities and processes that will be represented into the conceptual model. We then detail this conceptual model (section 3) and the possible cases of the use of this model. Modelling choices are then discussed (section 4) towards the general purpose of the project and particularly the social conflicts issues linked to water resources.

1. Modelling Stakes Regarding Social Conflicts on Natural Resources

A model is a simplification of a real object that enables an observer to answer questions about the real object [10]. As being a simplification, a large part of the modelling challenge involves the choice of what will be described in the model and what will be rejected.

Agent-oriented modelling reuses the social metaphor of multi-agent systems for describing social dynamics. The basic principle is to represent stylised autonomous entities – the *agents* – in interaction within an environment. Agent-based modelling is especially suitable for modelling social dynamics [11]. Once the socio-environmental system is described with an agent-based model, simulation is used to study the evolution of this “artificial world”. Among others, agent-based models are readable (one can understand what happens in the model) and offer more flexibility than mathematical models.

In the case of conflicts related to water resources, agents in the model may represent water users (e.g. cultivators or industry) as well as institutions involved in the water management process. The environment may include water dynamics, cities, forests, more or less complex ecosystems and so on. The challenge of modelling is precisely to *choose the boundaries of the model*, that is, what should be described and what may be ignored. As a general rule, a model should be kept as simple as possible. However, the model has to be descriptive (~realism) enough to fulfil its purpose. Modelling is thus the difficult search for a relevant trade-off between descriptivity and simplicity. Moreover, the model should comply with other constraints inherent to the purpose of the model.

The general use of the model is as follows. For each specific field case involving conflicts related to water use, the model should enable the description of the case (environment, users and regulators). It should then support the exploration of various scenarios intended to help decision makers to choose the most relevant strategy for a given case.

As a consequence, the model developed in the MAELIA project should be *generic* enough for it being applied on various field cases with as few changes as possible. Planned cases include the Adour-Garonne basin in France and in further works, the Gauvery basin in India and the Amazonian basin. In this context, genericalness implies various constraints. *The model should be scale-free*, so that it may be instantiated on a case involving only a small river and several hamlets as well as at the scale of an entire

basin. Both the biophysical component and the social layer may then be described at these various scales.

We start building this generic model by describing the case of the Adour-Garonne basin in France, for which detailed observation are available for both the water system and behaviours related to water consumption. The description of this case enables to anchor the model in a real case; the conceptual model proposed for this case is however developed to be as generic as possible.

2. Building a Generic Model Using the Adour-Garonne Case Study

2.1 The Social Management Organisation of the Adour-Garonne Watershed Basin

The Adour-Garonne basin is the basis of an administrative framework that is in charge of the basin water management since the Water Law and the creation of the basin authorities or “Water Agencies” for each basin in 1964². The basin is positioned in the south west of France and corresponds roughly to one fifth of the French metropolitan territory (see Figure 1). It actually comprises the watersheds of the river Garonne and its tributaries but also of the Charente and the Adour rivers.

In this section, we build taxonomy of actors involved in water management by using the Adour-Garonne case as an inspiration for a more general conceptual framework. To build a generic model that can integrate several elements of the social part of a river watershed, we reuse observations from general literature on water management but also from the “grey literature” concerning several real sub-basin cases of the Adour-Garonne basin.

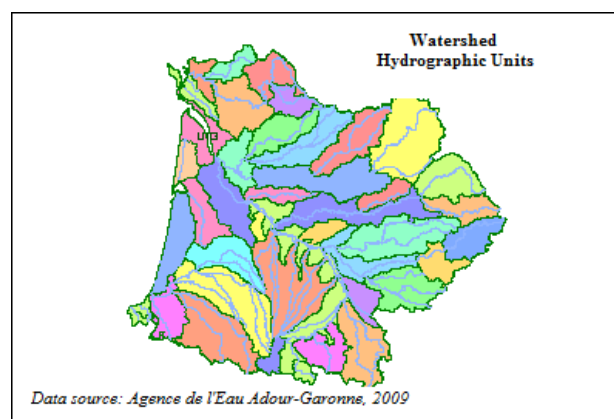


Figure 1. Hydrographic sub-basins of the Adour-Garonne watershed

² “Loi du 16 décembre 1964 relative au régime et à la répartition des eaux et à la lutte contre leur pollution”

Humans can then be seen as *individuals acting for their own benefit* but also as *representatives of institutions/organisations*. One may note that no individual on his/her own has the social capacity to be in charge of the management of a resource or a portion of the use/problems concerning this resource and to be the user at the same time. Therefore, we combine these two elements: we separate water users and water managers as two blocks dealing one with another. One may notice that some actors in some watersheds have both positions. For instance, hydro-electric dam managers may be seen as both users and managers. Meanwhile, as described by [12], once they deal with public/institutional actors, they can be considered as water users: their management actions (e.g. opening the dam to feed a river with water) follow institutional/elective authority procedures. The main difference between these two blocks of actors is that users consider their world following only individual and “local” attributes and indicators, while managers include common attributes and indicators. This does not mean managers are pure altruistic public officers while users are pure egoistic actors: the latter follow their indicators and attributes from the group they belong to. The former are combining equivalent attributes and indicators but also the ones corresponding to water issues they are supposed to manage.

2.1.1 Elected Authorities

The Adour-Garonne basin, as well as the whole territory of metropolitan France, is subdivided into provinces (in French “Régions”) that group several districts (in French “Départements”) and finally communes ruled by an elected mayor and the municipal council. The first two levels are both ruled by a prefect nominated by the government and managed by a corresponding elected council and its presidents (see Figure 2 for elected structures in yellow [13]). The Adour-Garonne basin includes two provinces in their whole, with portions of four other provinces, many districts and thousands of communes of various sizes. These elected administrative structures are in charge of almost all the aspects of territory and population. Decentralisation provided for transfer of duties between the central government and local administrative units without the allocation of additional funds, however. It means that democratic bodies that are actually in charge of environmental issues are not the ones having regalia powers of law production and “legitimate force”. We shall call these elected public organisations “elected authorities”.

Following the French administrative system and simplifying it for facilitation purposes, we can differentiate these authorities according to the territory and the population type they correspond to:

1. Elected authorities ruling only rural population that can be assimilated to senate-electoral districts;³
2. Elected authorities ruling only urban population or a mixture of both urban and rural areas, which can be assimilated to the National Assembly Deputies electoral districts.

The differentiation between elected and non-elected public services is not obvious: examples can be found that show that non-elected institutions may be influenced by lobbies. But, as noticed by [7], this happens mainly in cases of high-level positions that

³ Actually, French senators are indirectly elected through members of a college of grand electors (mayors and other locally elected people). Senators are representing the whole territory but there is a strong overrepresentation of rural areas-originating senators in senate.

are well-connected to governmental groups, meaning they have a high probability to shift with governmental transitions. Meanwhile, such events may appear (for instance, new norms that do not interfere with big companies' benefits) but this does not concern our research purpose here, i.e. locally connected water conflicts. This shows, however, that our assumption is simplifying. Anyhow, we consider that the above differentiation may improve understanding of gaps between the official, upper-level originated norms that are officially promoted and monitored by public institutions, and the management of these norms, which is commonly and *de facto* performed by other institutions. Several field based examples show that these norms are not strictly applied: the way they are put into application is thereby also an important stake on which users' lobbies have strong powers, which we take into account through the above assumption. We define elected organisations/institutions as elected collective entities in contrast to the non-elected pro-environmental organisations that we define as "water institutions".

2.1.2 Water Institutions

As shown in Figure 2, several public services are under control of prefects at different levels to fulfil different purposes (for instance, the DRAF is the Regional office for Agriculture and Forestry and the DDAF is the equivalent office at the Département level). These structures are filled in blue in Figure 2. We name such organisations "water institutions" as in this model we only consider the institutions in charge of the environmental issues. Therefore, it means that designated offices in charge of the environmental and infrastructural aspects do not belong to locally elected authorities but to governmental public services, allowing them independence from local powers, but also placing them "into gaps" between government-level rules and schedules and the local ones.

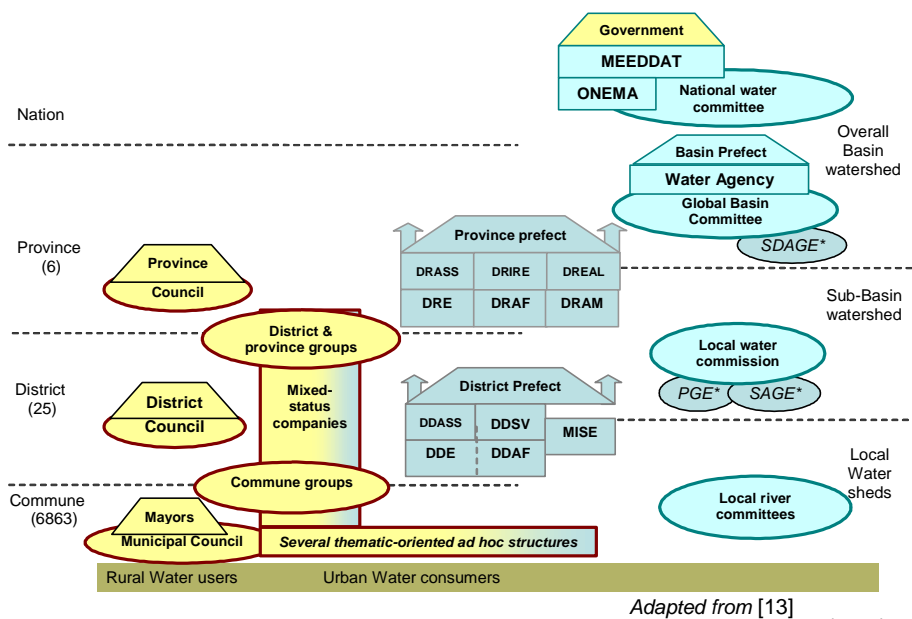


Figure 2. The framework of different institutions, organisations and dedicated public offices in charge of water management of the Adour-Garonne watershed basin

Meanwhile, the 1964 and the 1992 Water Laws have acknowledged the necessity of cooperation based on collegiality, introducing thereby assemblies at different water-related watershed levels (see blue ellipses in Figure 2). These collegial assemblies are in charge of negotiation of the whole basin SDAGEs (Water Management Ruling Frameworks) and sub-basin SAGEs (Water Management Frameworks) and PGEs (Lowest Water Management Plans), dedicated to plans and rules regarding water issues [14]. However, these assemblies remain only consultative. For the sake of simplicity, we also include them as “water institutions”. As a consequence, we stylised all the institutions depicted in blue in Figure 2 as one unique water institution.

The last twenty years have seen many management structures created by different institutions, mainly at the sub-basin and the commune levels, to improve connections between public water institutions and elected authorities. Among these local structures, depicted in mixed blue and yellow in Figure 2, some are under private status but with public ownership and others are under public rule. As their role is out of the scope of our study, we do not represent them into the model.

2.1.3 Urban and Rural Users

Finally, we differentiate the water users of the Adour-Garonne basin according to the main way they consume water, but also according to the urban/rural duality, into mostly *urban consumers* on the one hand and mostly production-related water users named *rural water users* on the other. *Urban water consumers* include industrials that are combined with citizens, as the latter are represented by water sanitation services, either public or private-owned. *Rural water users* group are farmers who constitute 80% of the consumed water in the Adour-Garonne basin. We thereby include industrial plants in rural areas as managed and linked to urban areas.

We fully acknowledge that water users such as farmers are obviously also water consumers. One may naturally envision the possibility to build agents that combine both characteristics, i.e. using and consuming water. This discrimination is connected to a more spatial one: urban and rural actors. Thereby, three categories of agents are built: we assimilate rural water users to farmers, while we also acknowledge that many large industrial plants (for instance nuclear plants) are usually spatially positioned in rural areas. Urban consumers (i.e. family/individual water consumers) and water users constitute the two last groups. As we have seen previously, they are both artificially restricted to urban areas. Meanwhile, they all combine the fact that they determine their attitude toward public actors (i.e. institutions and elected collective entities) according to their own specific access to the resource, even if, once they are unsatisfied, relationships between the avatars belonging to the same entity type are introduced to simulate the influence of groups of such users and consumers on public managers.

2.1.4 Summary of the Actors Taxonomy

As shown during this description of the actors in the Adour-Garonne basin and following [15], a lot of institutions are implied in water management. We built a simple taxonomy of four main types of agents: water institutions, elected authorities and rural/urban consumers. We will next formalise the relationships that link elected authorities and their electors, i.e. rural and urban users. As will be discussed later, these four main types of actors are present in most field cases, and may be viewed as quite generic.

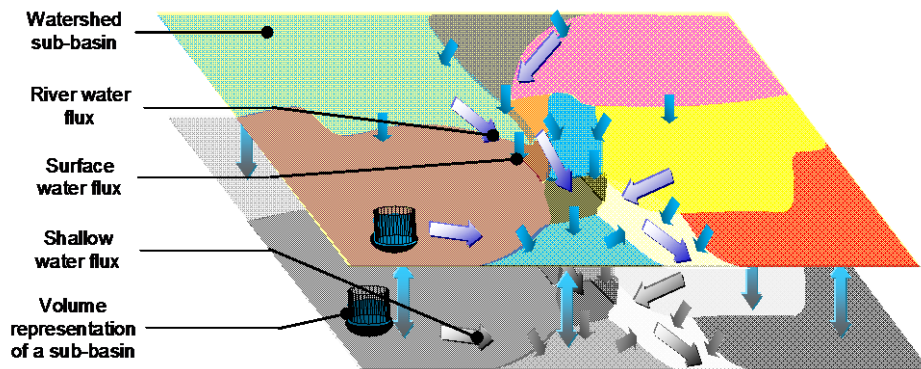


Figure 3. The biophysical dimension of the MAELIA project model

2.2 A Generic Model Framework for Simulating Water-Related Social Relations

2.2.1 The Biophysical Environment

We develop a biophysical formalism for the model that is based on spatial discrimination according to both physical watersheds and political/administrative entities.

On a practical point of view and as shown in Figure 3, the whole basin is simulated through a spatial grid of cellular automata, each automaton corresponding to a portion of space described by several attributes that are biophysical (watershed belonging, land use type i.e. crop production or human occupancy) and social (belonging to administrative units). The whole basin is subdivided into sub-basins corresponding to rivers and river sections in order to avoid the overlap of flows between watersheds. For instance a subsection may concern the river between the upper confluent and the lower one (Figure 3).

The basin is also subdivided according to administrative units that are classified as “urban” or “rural”, building thereby the territory of elected authorities, rural and urban. Another level of elected administrative units groups a rural and an urban entity to create a mixed level. With these three types of districts that are ruled by “elected” agents, we simulate different unit types one can observe within a watershed basin, at whatever scale: such a discrimination can be applied at the scale of the whole Adour-Garonne basin but also at lower scales for more local case study purposes.

Each sub-basin corresponds to a shallow sub-basin which has the same territory for the purpose of simplicity. Water exchanges can then be estimated between different sub-basins assuming that they are directed: for instance juxtaposed watersheds are not supposed to exchange water while they exchange water with their respective shallow basins and with their lower river section-corresponding sub-basins. Following this hierarchy, another flow follows the river network. Thereby, two flows simulate the observed fluxes of the basin, one through the rivers network and one through the watershed basins network.

We consider decade (i.e. 10 days) as the most relevant time step for integrating further data from real water institutions describing water fluxes.

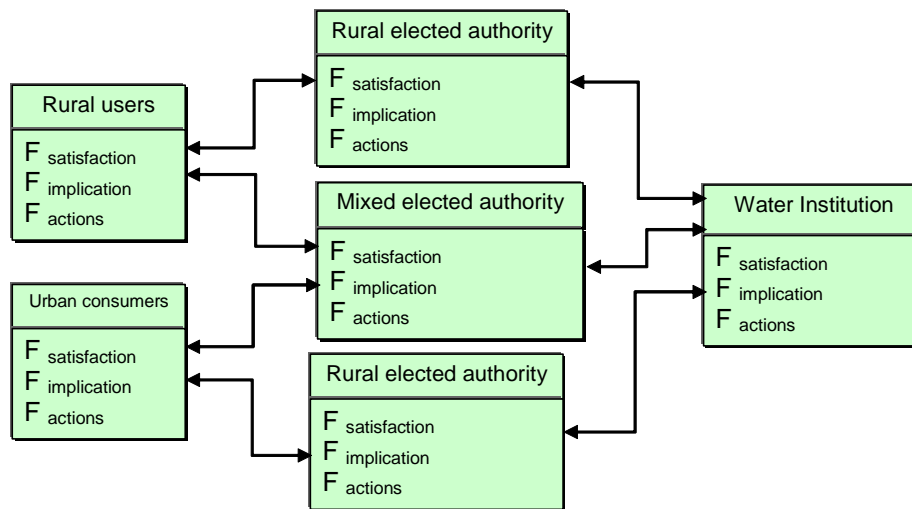


Figure 4. Diagram of human and/or institutional entities of the MAELIA project model

2.2.2 The Agents' Behaviour

Once the biophysical and social frameworks are established, we now present the relationships we built to simulate connections between agents. All agent types follow rule functions that link their behaviour depending on their perception of the environment and their motivation. The non-spatial entities, i.e. the agents that are simulating human and/or institutional actors are presented in Figure 4:

Each agent type bases its future behaviour on a *first function of satisfaction*. This function varies according to the agent type:

- a. Rural water users, i.e. farmers, have satisfaction based on their individual water need fulfilled, but also on the satisfaction level of their co-avatars belonging to the same electoral district in the model;
- b. Urban water consumers follow the same rule based on their own (smaller) individual needs and satisfaction of co-citizens of the same district;
- c. Water institutions base their satisfactions on a ratio following the average water level in the river corresponding to each sub-basin, creating thereby as many satisfaction functions as rivers and river portions. The ratio corresponds to the quotient between the needed water level for the corresponding time step and the present one;
- d. Elected authorities have a satisfaction function combining the satisfaction of their electors, the satisfaction of their fellow elected (rural or urban) authorities and the effect of their fund level fulfilled. For this last point, as funds come from the water institution (practically, the funds are provided once the water institution agrees for this support), we thereby somehow simulate the necessity for elected authorities to integrate the environmental aspects into their actions.

A second function corresponds to the *agents' involvement*, thereby named the *implication function*. Following the involvement principle of [15], this function helps to

discriminate between the actors who make the decision to act/react facing a threat or a challenge. This action function combines several factors but in our simulation we take into account only external ones – we do not consider human internal factors such as personality or belief differences, i.e. we treat all agents of the same category as equivalent. This function also varies according to the agent type:

- a. Farmers see their implication growing once their fellow farmers belonging to the same district are “unsatisfied” as well: the more the proportion of fellow unsatisfied farmers is important, the more the implication function grows. The same function grows with the number of consecutive time steps the farmer is unsatisfied. We thereby simulate anger accumulation but also the connection network within a union for common actions;
- b. Urban water consumers follow the same rule. Because we include a large population within urban areas, we thereby simulate a far smaller connection network within the population of a same urban district;
- c. As the water institution has always the same behaviour following the water level improvement principle, we do not implement any additional implication function;
- d. Finally, elected authorities see their implication function as a combination of the dissatisfaction of their “electors” (the more the proportion of their “unsatisfied” electors grows, the more the implication function grows), the dissatisfaction of their fellow elected authorities (only rural elected authorities for rural ones, only urban elected authorities for urban ones) and the number of time steps since the water institution cut the fund flows necessary for the authority budget (the more time with no fund flows passes by, the more the implication for action on environmental issues grows).

Once the agents’ satisfaction and/or implication functions pass thresholds, they act according to the following rules:

- a. Once a farmer is “unsatisfied”, his implication function grows. Once this function passes a threshold, he impacts the satisfaction functions of his co-avatars, increasing their dissatisfaction. Once the second threshold is passed, combined with another threshold based on the number of unsatisfied co-avatars, the satisfaction of “his” elected authority starts to decrease. Because the implication function continues to grow after that level until the access to water is available, once the last threshold on this function is passed, the farmer disobeys the rules of the water institution and therefore does not restrain the use of water;
- b. Urban water consumers have the same reaction. Again, as there is a larger population in urban areas, we thereby simulate a far smaller connection network within the population of the same urban district;
- c. The water institution, based on the water ratios, provides limitations to water users and/or consumers for the different sub-basins and districts. Two levels are determined for each sub-basin: below the first level in a sub-basin, the concerned users and/or consumers are asked to reduce their water consumption, thereby possibly increasing their dissatisfaction and even making them disobeying. Below the second level, the concerned users and/or consumers are asked to stop their consumption. Elected authorities are considered responsible. As the water institution provides funds to elected

authorities on a regular basis, if one of these authorities sees its “electors” not implementing these water limitations the institution imposes, the institution reduces progressively the funds, thereby increasing the dissatisfaction of the concerned elected authorities.

- d. Finally, the elected authority has one possible reaction: after a time of crisis during which some users and/or consumers do not implement the water use reduction rules the water institution may provide, the elected authority can give an amount of money equivalent to the loss users/consumers have, reducing thereby their dissatisfaction and stopping their disobedience.

To summarise and as shown in Figure 5, all the agents act given their perception of the environment and their motivations; these motivations are based both on the states of other agents and on the state of the resource. Given their satisfaction functions, user agents are more sensitive to the state of the resource (given their needs), while elected agents are more focused on the satisfaction of the users they represent.

3. Modelling a Watershed Basin and Water-Related Social Relationships: What For?

As noticed earlier, the model is purpose-oriented. We build the modelling scheme for answering two sets of questions related to rather complementary goals. The model we present in the previous sections is more relevant once we couple it to an already conceived agent-based tool based on a robust, empirically grounded sociological theory: the sociology of organised action [16; 17]. The purpose of this SocLab (Sociology Laboratory) tool is to allow the simulation of “concrete systems of action” [18]. Beyond the formalisation of what is tacit and/or qualitative in the theory, this modelling tool helps exploring analytically the space of the possible states of a social game within such a “concrete system of action”.

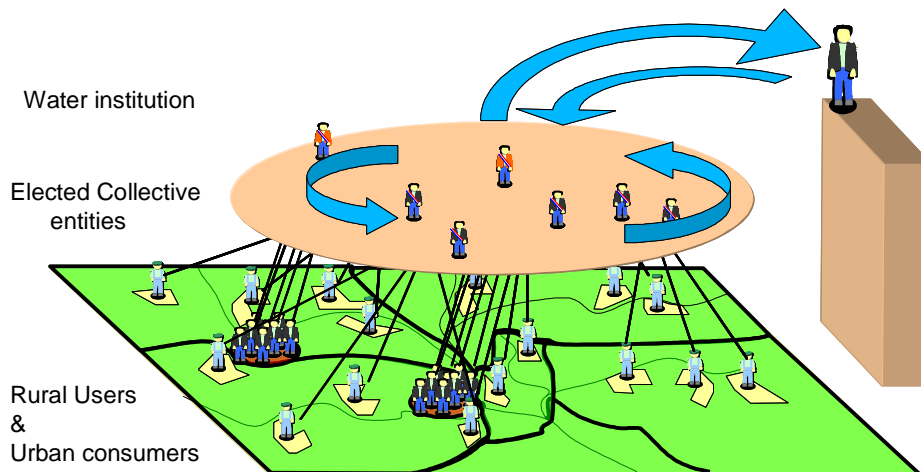


Figure 5. The different agents of the MAELIA project model

The first difficulty is thereby to enclose such a system, i.e. to define the limits within which remain only the actors that have an influence/impact on a particular stake, in our case a water-related issue. Simulation helps thereafter to consider the emergence of a regulation by indicating the states on which the social game is stabilising. Such a tool allows building some confidence in organisation studies and thereby enriches the study of the possible states of a social system. Formalising sociology both methodologically and analytically is a powerful way of improving sociologically-acceptable decision-support tools, even with some unavoidable simplification [19]. This tool may thereby help to suggest in which direction a social system may go, not for the common “greater good” but for the most probable direction according to the local balance of powers amongst actors. This entails, however, a deep investigation of which powers are genuinely and practically acting on a social issue, i.e. which variables are to be integrated into the model and then to parameterise such variables with field-originated quantitative data and qualitative information.

Following the two complementary purposes, we propose to integrate this tool in our methodology along two ways, as follows.

3.1 Comparing the Impact of the Implementation of Different Norms

The purpose of the methodology is here to follow a very common framework of scenario comparison: Each scenario is based on a set of norms and we compare the simulation outputs of the norm-based scenario *ceteris paribus*. In our case and for answering the main question we try to answer, this set of norms means a share of the rights and duties to fulfil between different agent types in the model. This set cannot evolve and the simulation reproduces the evolution of both the biophysical environment and the social system, namely the satisfaction and the implication functions of the different agents as well as their reactions.

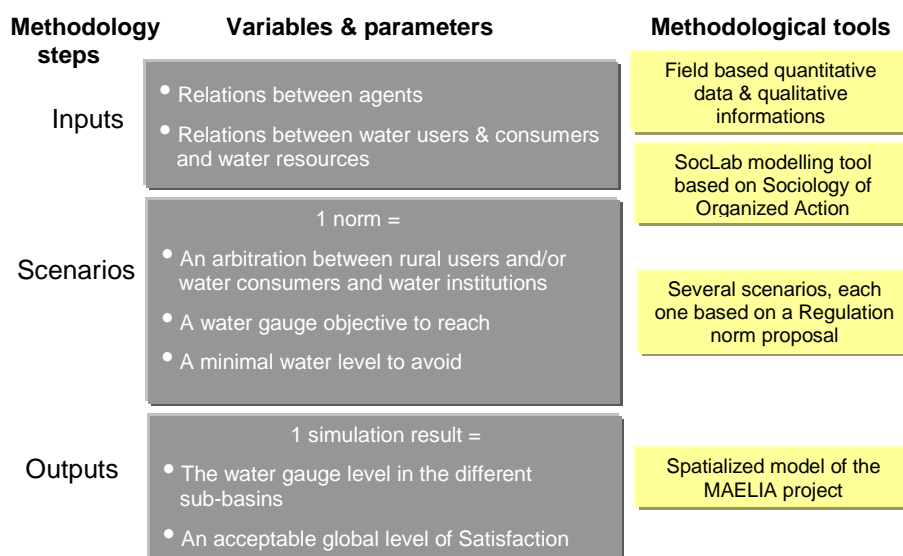


Figure 6. The first purpose of the MAELIA project methodology: Comparing norm-based scenarios

As shown in Figure 6, the SocLab tool helps to formalise the relationships between different agent types and avatars while these relationships are defined from field sociologically based investigations.

3.2 Assessing the Formulation of Norms Based on Concrete Systems of Action

Here we propose to simulate the formulation of a norm through the evolution of the balance of powers between the agent types and avatars. The spatialised model of the MAELIA project integrates the biophysical environment and constraints waters users and consumers encounters. The initial norm, i.e. the water arbitration, is set according to field observations. The simulation purpose is to determine the evolution of the balance of powers between the agent types and avatars that will define the evolution of the local norm itself. It means consequently to build a process on which for each state the balance of powers that is suggested by the SocLab approach corresponds to a configuration of rights and duties, i.e. a regulation norm related to water in our system. This process is yet to be fully settled. We consider the possibility of a multivariable set of combinable possibilities with scrolling menus, each one linked to a qualitative level of power, describing altogether the different norm possibilities as proposed in the following example:

*All / only violator / only recidivist violator / other possibilities ...
Rural users / urban consumers / all water users & consumers ...
have to ...
pay a tax / reduce by X% / stop consuming water
during X time steps.*

Therefore, the methodology follows a process as shown in Figure 7, where the SocLab tool and the multivariable set are the integrators of the relationships between different agents, with these relationships determined and conditioned by the social and biophysical environment and constraints as displayed by our MAELIA project spatialised tool.

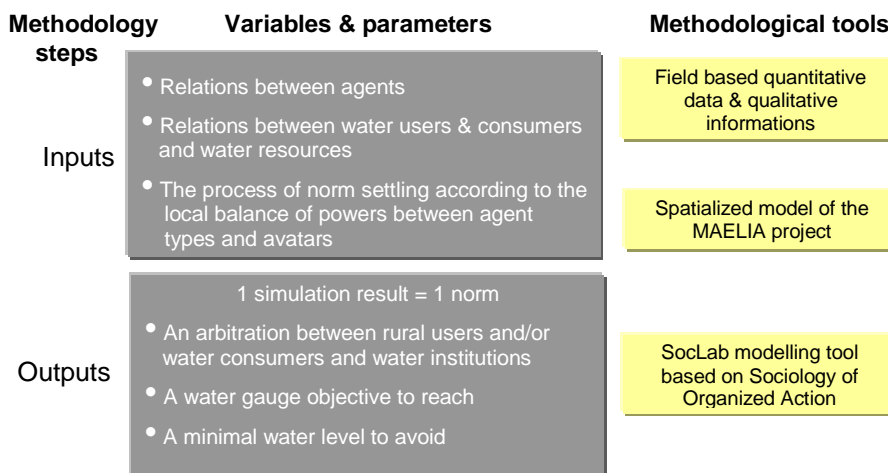


Figure 7. The second purpose of the MAELIA project methodology: Assessing norm formulations according to local balances of power amongst agent types and avatars

4. Discussion and Conclusion

4.1 Summary

In this paper, we tackled the challenge of coupling social and biophysical dynamics into a unique model. We are looking for a simple solution usable for describing different socio-environmental cases at various scales. While most existing models study objective resource scarcity and suppose that negotiation of norms is based on this scarcity [20], we base the negotiation of norms on subjectively perceived scarcity and on the balance of powers among actors. This negotiation takes place between institutional actors, some of them being in charge of representing categories of users. We proposed a conceptual model that includes both the social and the hydrological component.

4.2 Benefits of the Proposed Formalism

As stated before, we kept the model as generic and flexible as possible. The hydrological system is described as several interconnected “tanks”, with transfer functions defining how water shifts from one reservoir to another. While remaining simple, this description enables the description of any case with tuneable granularity. Tanks may be described for groundwater, surface water and (if relevant) atmospheric water. Transfers between these three main types of tanks correspond to infiltration, evaporation and so on. A finer granularity may be used if useful, by multiplying the number of tanks. Each river may be described as various sections. Complex dynamics of groundwater may also be described with several tanks. Describing complex bidirectional transfers between groundwater and the river is also possible if relevant. We are currently formalising the water system in the Adour-Garonne Basin using the data from the Geographical Information Systems. In this larger case, only the larger water masses are described: main rivers, and one aquifer per sub-basin. After simulations and advice from experts, this stylised description will be complexified when relevant.

Genericalness is by far more challenging when tackling social dynamics, due to the inherent variety and complexity of social processes [21]. We retained only the entities and social processes that exist in any case. We proposed taxonomy of *the four main types of actors* that may be identified in most cases. Any field case involves users willing to satisfy their needs, authorities who have to regulate the quantity and quality of the resource while keeping the satisfaction of their people at a viable level, and “environmentalists” fighting for a better quality of the resource. These four main types of actors can be instantiated for each specific case. The *behaviour of agents* depends on the state of resource (whether it enabled them to satisfy their needs or not) and on their relationships with other actors. For instance, actors representing other users try to maintain the satisfaction of their electors. This dual view of actors’ motivation is also quite generic: any user, or manager, monitors both the resource and its social or institutional environment.

This conceptual model appears to be a totipotent and generic solution for describing conflicts related to water, which is so particular because it is a vital and non-replaceable natural resource for locals, and thereby a locally vital social stake.

4.3 Further Work

We are currently applying this conceptual model to the Adour-Garonne basin. The hydrological conceptual model will be instantiated with the help of hydrologists. We are also studying the best formalism to describe existing norms in this region. The behaviour of water users will be parameterised given statistical data from the research institutions in charge of the agricultural studies. Without any doubt, this instantiation of the generic conceptual model for this specific case, as well as the implementation of this model and subsequent simulations, will highlight limits of the model.

We build a model that will be used for decision-support. The model is thus designed for a “customer” [22], here a decision maker, which will manipulate the model for exploring various scenarios. Acknowledging this benchmarking approach is a primordial step for any decision support tool, as no real tool can reproduce the reality as a whole.

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References

- [1] T.F. Homer-Dixon, J.H. Boutwell and G.W. Rathjens, Environmental change and violent conflict, *Scientific American* (February 1993), 38-45.
- [2] I. Van der Molen and A. Hildering, Water: Cause for conflict or co-operation?, *ISYP Journal on Science and World Affairs* **1** (2005), 133-143.
- [3] UNESCO, *The United Nations World Water Development Report: Water in a Changing World*, UNESCO, Paris, 2009.
- [4] A.T. Wolf, S.B. Yoffe and M. Giordano, International waters: Identifying basins at risk, *Water Policy* **5** (2003), 29-60.
- [5] P. Barret, A. Gonzalez, Y. Barret, C. Olivier, *Société civile et résolution des conflits hydriques*, Programme PCCP Technical documents in Hydrology, UNESCO, Paris, 2003.
- [6] H. Kieken, Le rôle des modèles dans la gestion de l'environnement, *10th Rochebrune Rencontres interdisciplinaires sur les systèmes complexes naturels et artificiels: Le Statut épistémologique de la simulation*, Rochebrune, France, 2003.
- [7] J.R. Lund and R.N. Palmer, Water resource system modelling for conflict resolution, *Water Resources Update* **108** (2008), 70-82.
- [8] E. Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge University Press, Cambridge, 1990.
- [9] J. Bryant, Modelling conflict over natural resources issues, *Resources Policy* **7** (1981), 39-44.
- [10] M. Minsky, Matter, mind and models, in: *Proc. International Federation of Information Processing Congress 1965*, vol. 1, Spartan Books, Washington, 1965, pp. 45-49.
- [11] D. Phan and F. Amblard, *Agent-Based Modelling and Simulation in the Social and Human Sciences*, The Bardwell Press, Oxford, 2007.
- [12] J-B. Nancy and L. Mermet, Nouvelles justifications pour une gestion spatiale de l'eau, *Natures, Sciences, Sociétés* **11** (2003), 135-145.
- [13] L. Verdier, *Retour d'expériences sur des dispositifs de concertation et de négociation au sujet du partage de la ressource en eau sur le bassin amont de la Garonne*, M.Sc., AgroParisTech Economie du Développement Durable, de l'Environnement et de l'Energie, Paris, 2009.
- [14] A. Brévier and S. Becerra, *La gestion quantitative de l'eau dans le Bassin Adour-Garonne: Rapport intermédiaire sur la gestion des étiages sur le bassin de la Garonne*, Programme MAELIA, LMTG, Toulouse, 2009.

- [15] T. Kirat, A. Torre, A. Aviles, A. Caron, C. Lefranc, M. Galman, R. Melot, C. Rialland and M.I. Salazar, *Modalités d'émergence et procédures de résolution des conflits d'usage autour de l'espace et des ressources naturelles. Analyse dans les espaces ruraux*, Report of the Research Programme "Territoires, environnement et nouveaux modes de gestion: la 'gouvernance' en question", CNRS-INRA, France, 2004.
- [16] M. Crozier and E. Friedberg, *L'acteur et le système. Dynamiques de l'action collective*, Seuil, Paris, 1977.
- [17] E. Friedberg, *Le pouvoir et la règle: Dynamiques de l'action organisée*, Seuil, Paris, 1993.
- [18] C. Vautier, P. Roggero, F. Adreit and C. Sibertin-Blanc, Evaluation by simulation of the social acceptability of agricultural policies for water quality, in: I.N. Athanasiadis, P.A. Mitkas, A.E. Rizzoli and J. Marx Gómez (Eds.), *Information Technologies in Environmental Engineering*, Proceedings of the 4th International ICSC Symposium Thessaloniki, Greece, May 28-29, 2009, Springer, Berlin, 2009, pp. 478-490.
- [19] P. Roggero, C. Sibertin-Blanc, M. Mailliard, F. Adreit, C. Vautier and S. Sandri, *Formalisation, modélisation et simulation orientée agents des systèmes d'action concrets: approche complexe de la sociologie de l'action organisée*, Report of the IRIT – CIRESS, Cerisy, 2007.
- [20] M. Hare and P. Deadman, Further towards taxonomy of agent-based simulation models in environmental management, *Mathematics and Computers in Simulation* **64** (2004), 25-40.
- [21] B. Edmonds and S. Moss, S. From KISS to KIDS: An 'anti-simplistic' modelling approach, in: P. Davidsson, B. Logan and K. Takadama (Eds.), *Multi-Agent and Multi-Agent-Based Simulation, Joint Workshop MABS 2004, New York, July 19, 2004, Revised Selected Papers*, Springer, Berlin, 2005, pp. 130-144.
- [22] K. Daniell, N. Ferrand and A. Tsoukiàs, Investigating participatory modelling processes for group decision aiding in water planning and management, in: S. Seifert and C. Weinhardt (Eds.), *Group Decision and Negotiation*, International Conference, Karlsruhe, Germany, June 25-28, 2006, pp. 207-210.